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(54) Outwardly mounted nozzles for rotary drill bits.

(57) A rotary drill bit (10) has fluid discharge nozzles (36A, 36B, 36C) positioned between adjacent pairs of roller cutters (20A, 20B, 20C). A fluid discharge nozzle (36A) positioned along the outer circumference of the drill bit body (12) provides a high velocity stream of drill fluid (44) along the bore hole side wall (34) with at least a substantial side portion of the stream (44) engaging the side wall (34) adjacent roller cutter (20A) and flowing downwardly along the side wall (34) across the bore hole corner surface (33). The nozzle orifice (37) has its center (41) positioned less than one inch from the adjacent bore hole side wall (34) and the stream is directed downwardly to provide a minimal change in direction as the stream (44) sweeps across the corner surface (33) and the bore hole bottom surface (32).

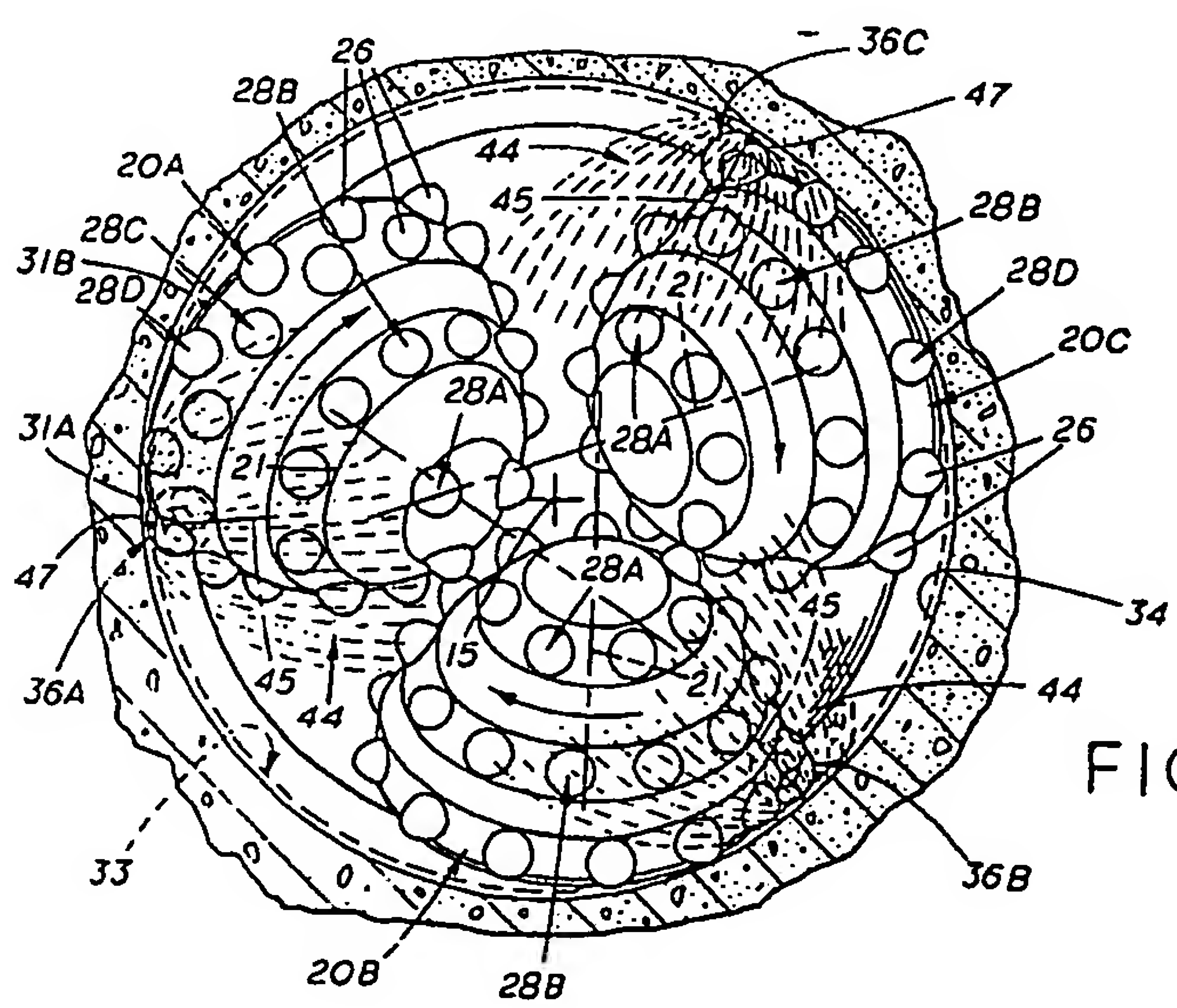

FIG.5

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BACKGROUND OF THE INVENTION

This invention relates to rotary drill bits for drilling oil wells and the like, and more particularly to an improved hydraulic action of drilling fluid against the roller cutters and particularly for the gage row of cutting elements and the corner surface of the earth formation being drilled.

While conventional drill bits have been satisfactory for drilling relatively brittle formations, they do not provide satisfactory rates of penetration when drilling relatively plastically deformable formations. Many commonly encountered formations such as salts, shales, limestones, cemented sandstones, and chalks become plastically deformable under differential pressure conditions when the hydrostatic pressure of the column of drilling fluid bearing on the bottom and corner of the well bore exceeds the pressure in the pores of the formation surrounding the bore.

In addition to compressive strengthening of plastic formations, high drilling fluid pressure causes the well known "chip hold down" phenomenon, where rock cuttings formed by the bit teeth are held in place by the pressure on the bore hole surface resulting in regrinding of the cuttings and decreased penetration rates. Weighting particles and drilled formation particles entrained in the mud increase the severity of chip hold down by blocking the flow of drilling fluid into the formation fractures and pore spaces, thereby restricting equalization of the bore hole and formation pore pressures and preventing chip release. In many impermeable formations such as shale, only a relatively small amount of fine particles is sufficient to seal off the formation fracture openings and severely limit chip removal.

Under these conditions "bit balling" often occurs where the reground cuttings and solid particles remaining on the hole bottom tend to adhere to the roller cutter, particularly in "sticky" formations such as shales, limestones, and chalks. The cuttings and fine solids are trapped between the well bore surfaces and the teeth and body of the rolling cutter, thereby being compressed by the drilling weight applied to the cutter as it is engaged to cut the formation. Compression of the solids onto the cutter surface builds a hard coating between and around the cutting teeth, often of sufficient thickness to reduce the effective protrusion of the cutting elements and limit their drilling effectiveness.

Numerous attempts have been made to overcome chip hold down and bit balling tendencies by modifying the configuration of the hydraulic nozzles to improve the cleaning efficiency and distribution of the drilling fluid energy. In U.S. Patent No. 2,192,693, Payne describes a rolling cutter bit with an open hydraulic passage near the center of the bit body which flushes drilling fluid over an outer gage row of teeth. The hydraulic passage directs a relatively low velocity stream of drilling fluid directly toward the uppermost portion of the cutter to achieve a flushing action normal to the body of the rotating cutter.

Bennett in U.S. Patent No. 3,618,662 dated November 9, 1971 provides an extended enclosed passageway for directing the drilling fluid centrally of a roller cutter to a point adjacent the teeth at the bottom of the hole. The flow channel for the drilling fluid after striking the side wall is directed downwardly while enclosed by the leg and the adjacent side wall until exiting closely adjacent the corner of the bore hole at the center of the roller cutter. Feenstra in British Patent No. 1,104,310 dated February 21, 1965 utilizes a jet nozzle formed by an end of an extended tube to direct a fluid stream downwardly at an angle of 30 to 60 degrees with respect to the axis of bit rotation and underneath the roller cutter at the outer row of teeth in cutting engagement on the bottom of the hole.

A method to improve hole cleaning without extended flow channels is shown by Lopatin, et al in Russian Patent No. 258,972 published December 12, 1969 where a rolling cutter drill bit has nozzle passages directed downwardly and radially outwardly against the side wall of the bore hole to strike above the bottom corner, providing an inwardly sweeping fluid stream having a high velocity across the corner and bottom of the well bore tangential to the formation surface. This design serves to clean solids away from the fracture openings at the surface of the formation, reduce the hold-down pressure on the fractured cuttings, and facilitate removal of dislodged cuttings by the high velocity fluid stream.

Childers, et al in U.S. Patent Nos. 4,516,642 and 4,546,837 employ a high velocity flow stream of fluid jet to first clean the cutting elements on a rolling cutter bit and then clean the formation at the bottom of the hole. The fluid jet trajectory passes the cutter tangential to its outer periphery with a portion of the jet volume impinging on the cutting elements and the remainder of the jet volume striking downwardly on the hole bottom underneath the cutter body slightly forward of cutting elements engaging the formation. The cleaning of both the cutter and the well bore bottom in separate and sequential actions provides improved penetration rates by attacking both bit balling and chip hold down. Deane, et al in U.S. Patent No. 4,741,406, add a modification to this concept in which the fluid jet cleans both the rolling cutter teeth and the formation with an improved flow pattern. High velocity fluid flows outwardly and downwardly to impinge upon the hole bottom, then turns upwardly

while moving toward the outer periphery of the hole, and next returns upwardly alongside the original nozzle exit in a spaced outer return channel for enhanced transport of cuttings away from the hole bottom.

SUMMARY OF THE INVENTION

The primary object of this invention is to maximize the penetration rate of rolling cutter drill bits by providing a hydraulic nozzle configuration for delivering a high velocity stream of drilling fluid to sweep across the corner surface and bore hole bottom with a minimum loss of energy to maintain the highest stream velocity with a substantial portion of the stream cleaning the cutting elements and the formation at the contact engagement area of the cutting elements with the formation.

This invention positions the nozzle for directing the stream downwardly and closely adjacent the side wall of the bore hole thus allowing a minimum change in direction of the stream, maintaining more of the discharge stream velocity as it sweeps around the corner surface and across the hole bottom. Special consideration is given to cleaning the gage corner surface where the formation is difficult to cut and balling of the teeth is prevalent. The gage row of cutting elements or teeth cut the side wall and diameter of the well bore, the outer periphery of the well bore bottom surface, and the corner surface between the side wall and bottom surfaces. The remaining rows of cutting elements cut the remaining bottom surface.

The outermost or gage row of cutting elements for each roller cutter is the row that most affects the rate of penetration of the rotary drill bit. The formation is stronger at the annular corner of the bore hole formed at the juncture of the horizontal bottom surface and the vertically extending cylindrical side surface of the bore hole formation. Thus, the outermost or gage row of cutting elements is the critical row in determining the rate of penetration. It is important that maximum cleaning action by the pressurized drilling fluid be provided particularly for the cutting elements in the outermost or gage row at the cutting engagement area of such cutting elements with the formation, and preferably at the cutting engagement area of other rows of cutting elements.

The nozzle discharge orifice is positioned at the outer circumference of the bit body close to the side wall of the formation and directed for the discharge of a stream of drilling fluid in a direction generally downwardly along the side wall and across the corner surface and hole bottom. Such a nozzle orifice position accelerates and directs a high velocity drilling fluid downwardly alongside the side wall with a substantial portion of the stream contacting the side wall and a major portion of the stream directed toward the corner surface adjacent the side wall so that a majority of the fluid sweeps first across the corner surface and then across the bottom surface. The high velocity fluid stream sweeps around the corner surface and along the hole bottom to scour the formation at the cutting engagement contact location of the cutting elements with the formation. While much of the prior art has provided some increase in penetration rates, it has been found that certain aspects of the nozzle position and direction of the fluid flow path therefrom are more important than expected.

Application serial no. 613,241 relates to a roller cutter drill bit in which a high velocity stream of drilling fluid is directed against the side wall and then sweeps around the corner surface at the cutting engagement contact location of the gage row of cutting elements with the formation.

The present invention likewise is directed to an improved hydraulic action for the cutting elements in the gage row. However, the drilling fluid is discharged downwardly from a nozzle orifice at the outer circumference of the bit body closely adjacent the bore hole side wall with the drilling fluid stream sweeping across the corner surface of the bore hole and then inwardly across the hole bottom with a minimum change in direction of the stream. Thus the stream loses a minimum of energy as it sweeps around the corner surface and across the hole bottom. A side portion of the high velocity stream or jet contacts the side wall above the corner surface so that a majority of the fluid scours the corner surface and sweeps across the bottom surface at the cutting engagement contact location of the cutters. The stream of drilling fluid is directed in such a manner that the velocity of the drilling fluid sweeping across the corner surface and under the cutting elements is not substantially reduced after impacting the corner surface of the bore hole so that adequate velocity is retained for the subsequent sweeping action. The high velocity stream after impacting the corner surface with at least a side portion thereof contacting the adjacent side wall sweeps with a thin high velocity sweeping action around the corner surface, and then beneath the cutter across the bottom hole surface to scour and clean the corner and bottom surfaces at the cutting engagement contact locations of the cutting elements.

The nozzle discharge orifices are positioned along the outer circumference of the drill bit body generally within one inch from the adjacent side wall of the bore hole. As the fluid discharge stream or jet from the nozzles is very close to the side wall when discharged from the nozzle orifice at least a side portion of the stream contacts the side wall as the discharge stream normally has a fan angle of

between five (5) degrees and ten (10) degrees. Thus, a substantial portion of the stream flows down the side wall above the corner surface for first sweeping along the adjacent side wall surface contacted by the adjacent reaming surface of the cutting elements in the reaming row, and then sweeping across the corner surface and the hole bottom.

It is a further object of this invention to provide a rotary drill bit having fluid discharge nozzles mounted along the outer circumference of the drill bit body closely adjacent the side wall of the bore hole for the discharge of drill fluid from nozzle orifices for flowing down the side wall with the stream sweeping across the corner surface and bottom surface of the bore hole with minimum loss of fluid velocity.

It is another object of the present invention to provide a rotary drill bit in which the center of a drilling fluid stream is directed toward an adjacent roller cutter in a generally vertical direction from a nozzle orifice at the outer circumference of the bit and closely adjacent the bore hole side wall with at least a substantial portion of the fluid stream flowing along the side wall and then sweeping across the corner surface at the contacting surface of the adjacent roller cutter with the formation.

Other objects, features, and advantages of this invention will become more apparent after referring to the following specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective of the rotary drill bit of this invention including three cones or roller cutters of a generally conical shape thereon and discharge nozzles along the outer periphery of the bit body;

Figure 2 is an axial plan view of the rotary drill bit of Figure 1 showing the three roller cutters with annular rows of cutting elements thereon and a nozzle adjacent each roller cutter at the outer circumference of the drill bit for directing drilling fluid toward the leading side of each roller cutter with the fluid flowing down along the side wall and between the corner surface and the gage surface of the roller cutter at the cutting engagement area thereof;

Figure 3 is a generally schematic view of the stream of drilling fluid taken generally along line 3-3 of Figure 2 and showing the drilling fluid directed downwardly against the corner surface of the bore hole with a substantial portion of the stream contacting the adjacent side wall for flowing around the corner surface and the hole bottom with a minimal loss of energy;

Figure 4 is a generally schematic view taken generally along line 4-4 of Figure 3 and showing the stream of drilling fluid directed downwardly in a vertical direction toward the leading side of an adjacent roller cutter;

Figure 5 is a bottom plan, partly schematic, of the streams of drilling fluid flowing downwardly along the side wall toward the associated cutters and then sweeping along the corner surface and inwardly across the hole bottom surface beneath the roller cutters;

Figure 6 is a schematic side view illustrating the stream of drilling fluid discharged from the nozzle orifice closely adjacent the side wall for flowing downwardly along the side wall, impacting the corner surface, and then sweeping across the hole corner surface and bottom surface in a thin high velocity tangential stream closely adjacent the bottom surface;

Figure 7 is an elevation looking generally along line 7-7 of Figure 3 with the formation removed but illustrated partially in broken lines;

Figure 8 is a side elevation of another embodiment of this invention in which a nozzle mounted at the outer circumference of the drill bit is angled slightly toward the side wall with the center of the stream striking the side wall above the corner surface for sweeping across the corner surface of the cutting engagement area of the gage row of cutting elements;

Figure 9 is a view looking generally along line 9-9 of Figure 8 and showing the high velocity fluid stream impacting the side wall above the corner surface; and

Figure 10 is a schematic view of a further embodiment of this invention showing a nozzle mounted on the outer circumference of a drill bit to direct a high velocity fluid stream toward a portion of corner surface positioned centrally of the adjacent roller cutter for striking the corner surface at the maximum penetration of the gage engaging surface of the roller cutter at the cutting engagement area thereof.

DESCRIPTIONOF THE INVENTION

Referring now to the drawings for a better understanding of this invention, and more particularly to Figures 1-2, a rotary drill bit 10 is shown in Figure 1 comprising a central main body or shank 12 with an upwardly extending threaded pin 14 and mounted for rotation about a vertical axis 15. Threaded pin 14 comprises a tapered pin connection adapted for threadedly engaging the female end of a drill string (not shown) which is connected to a source of drilling fluid at a surface location.

Main body shank 12 is formed of three integral connected lugs defining three downwardly extending legs 16. Each leg 16 has an inwardly and downwardly extending cylindrical bearing journal or shaft 18 at its lower end as shown in Figure 3. Roller cutters 20A, 20B, and 20C are mounted on

bearing shafts or journals 18 for rotation about longitudinal axes 21 and each roller cutter is formed of a generally conical shape as shown in Figure 3. Rotational axis 21 of cutter 20A as shown in Figure 3 intersects leg 16 at 23. Each roller cutter 20A, 20B, and 20C comprises a generally conical body 22 having a recess therein receiving an associated bearing journal 18. A plurality of generally elongate cutting elements or teeth 26 have cylindrical bodies mounted in sockets within body 22 and outer tips extending from the outer ends of cutting elements 26. Cutting elements 26 may be made of a suitable powder metallurgy composite material having good abrasion and erosion resistant properties, such as sintered tungsten carbide in a suitable matrix. A hardness from about 85 Rockwell A to about 90 Rockwell A has been found to be satisfactory.

Cutting elements 26 are arranged on body 22 in concentric annular rows 28A, 28B, 28C, and 28D. Row 28D is the outermost row and comprises the gage row of cutting elements 26 that determines the final diameter or gage of the formation bore hole which is generally indicated at 34. Row 28C is adjacent to row 28D and comprises an interlocking row on cutter 20A. Cutting elements 26 on row 28C are staggered circumferentially with respect to cutting elements 26 on row 28D and the cutting path of elements 26 on interlocking row 28C projects within the circular cutting path of row 28D. Thus, the cutting paths of the cutting elements 26 on rows 28C and 28D of roller cutter 20A overlap. It is noted that cutters 20B and 20C do not have interlocking rows as adjacent rows 28B are spaced substantially inward of row 28D and cutting elements 26 on row 28B do not project within the cutting path of 28D for cutters 20B and 20C. In some instances, it may desirable to provide two cutters or possibly all of the cutters with interlocking rows of cutting elements. As shown in Figure 3, the gage surface of roller cutter 20A includes a reaming surface 29 having a row 28E of generally cylindrical cutting elements 26A. The gage surface of roller cutter 20A includes reaming surface 29, reaming cutting elements 26A in reaming row 28E, and cutting elements 26 in gage row 28D.

Bore hole 30 includes a generally horizontal bottom surface portion 32 and an adjacent cylindrical side wall 34 extending vertically generally at right angles to horizontal bottom 32. The corner surface between horizontal bottom surface 32 and cylindrical side wall surface 34 is shown at 33 and has a 45° tangent through its center in Figure 6. The cutting elements 26 on gage row 28D engage the formation in cutting relation generally at the corner surface 33 formed between the generally horizontal bottom surface 32 and the generally vertical side wall surface 34, as well as adjacent marginal portions of side wall 34 and bottom surface 32 as shown in Figure 6. Also, gage surface 29 and cylindrical cutting elements 26A frictionally engage side wall surface 34.

The gage row 28D of cutting elements 26 are positioned to contact and cut side wall 34 of bore hole 30, surface 33, and a marginal portion of the outer periphery of bottom surface 32 while the remaining inner rows 28A, 28B, and 28C are positioned to contact and cut the remainder of the bottom surface 32. The rotational axes 21 of bearing shaft 18 may be offset from the rotational axis 15 of bit 10 as shown in Figure 2 an amount of 1/16 inch or less per inch of bit diameter as may be desired for the particular formation encountered.

Referring particularly to Figure 6, the projection of the lowermost cutting elements or teeth 26 in the outermost or gage row 28D and in the interfitting row 28C are shown schematically for engaging bore hole 30 in cutting relation. As shown in Figure 6, gage row 28D engages the formation in cutting relation at the corner surface 33 between the cylindrical side wall surface 34 and bottom surface 32. Several teeth 26 in gage row 28D may be in simultaneous cutting engagement with the periphery of bore hole 30 with a cutting elements 26 initially engaging side wall portion 34 on the leading side of cutter 20A at an upper point 31A and then disengaging bottom wall surface 32 as shown at lower point 31B in Figures 5 and 6. Initial upper contact point 31A is generally around 1/2 to 1-1 /2 inches above the lowermost contact point 31B of cutting elements 26 and spaced circumferentially along the bore hole from point 31B around 2 inches, for example. As bit 10 and roller cutter 20A rotate, cutting elements 26 in gage row 28D proceed downwardly along side wall surface 34 from upper point 31A. As cutting elements or teeth 26 move downwardly along side wall surface 34, the formation is cut with a dragging, shearing action at the outer surfaces of teeth 26 in gage row 28D. As teeth 26 approach their lowermost position, the amount of drag is reduced so that teeth 26 cut first the corner surface 33 and then cut a marginal portion of the bottom surface 32 of hole 30 with a partial scraping action and a partial crushing action. The cutting engagement of corner surface 33 is generally located at the lowermost position of the cutting elements in gage row 28D and is shown at point 35 in Figures 5 and 6 at the center of corner surface 33. Also, reaming surface 29 and cutting elements 26A in reaming row 29 frictionally engage side wall 34. Soon after proceeding past the lowermost position shown by tooth 26, the teeth disengage corner surface 33 and disengage hole bottom surface 32 at lower point 31B. Due to this intricate path, there are typically two (2) to four (4) teeth in gage row 28D engaged simultaneously at

different cutting areas along an arcuate cutting zone adjacent the lowermost tooth 26 including corner surface 33 and adjacent marginal portions of bottom surface 32 and side wall 34 between upper and lower points 31A and 31B. The distance E between the cutting points from the initial side wall contact at upper point 31A to disengagement on the trailing side of the cutter adjacent lower point 31B as shown in Figure 6 varies with such factors as the offset of rotational axis 21, the type of formation, and other drilling conditions.

In contrast to cutting elements 26 in gage row 28D, the cutting elements in inner rows 28A, 28B, and 28C engage only the hole bottom 32 with a relatively simple and comparatively short cutting path at cutting areas directly beneath the associated cutter. The cutting action occurs primarily as a vertical motion into and out of the formation, with a slight amount of drag across the hole bottom. Cutting engagement points for the cutting elements in gage row 28D and inner rows 28A and 28B are shown in Figure 2 at 39. The cutting elements in their lowermost cutting position are shown as broken lines in Figure 2. It is in this position that the corner surface and inner areas of the bore hole are cut. This occurs directly below the center of rotation of the cutter. These cutting engagement points are located in a generally L shaped pattern with the gage row cutting the side wall at the outer end of the pattern and the inner rows cutting the hole bottom at the inner end of the pattern. The corner surface 33 is cut at the corner of the L shaped pattern as shown particularly in Figures 5 and 6. This pattern of cutting locations provides an opportunity for substantial increases in rate of penetration provided that a fluid nozzle design is provided to maximize fluid cleaning action between the formation and cutting elements at their engagement locations.

To provide high velocity drilling fluid for the improved cleaning action, particularly for the gage contacting surface of the roller cutter which includes reaming row 28E of cutting elements 26A and gage row 28D of cutting elements 26, a directed nozzle fluid system is provided. The fluid system includes a plurality of nozzles indicated at 36A, 36B, and 36C with a nozzle positioned on the outer circumference of bit body 12 closely adjacent an associated roller cutter 28A, 28B, and 28C. Each nozzle 36 has a drilling fluid passage 38 thereto from the drill string which provides high velocity drilling fluid for discharge from a discharge orifice or port 37 through fluid passage 29A having its center at 41.

For the purposes of illustrating the positioning and direction of the nozzles and associated orifices for obtaining the desired flattening of the discharged streams of drilling fluid against the side wall for sweeping along the side wall and corner surface of the bore hole and hole bottom, reference is made particularly to Figures 3-6 in which nozzle 36A and roller cutter 20A are illustrated. It is to be understood that nozzles 36B and 36C function in a similar manner for respective roller cutters 20B and 20C.

Nozzle 36A has a nozzle body 40 defining discharge orifice 37 for directing fluid stream therefrom as shown at 44 in a vertical direction parallel to the axis of bit rotation. Fluid stream 44 is shown of a symmetrical cross section and having a fan angle of around 5 degrees to 20 degrees, for example, about the entire circumference of the stream with the centerline of the volume of discharged fluid shown at 45 and impacting corner surface 33 at impact point 47. Other fan angles or non-symmetrical cross sections for fluid stream 44 may be provided, if desired. Nozzle 36A preferably is positioned with discharge orifice or port 37 at a position between the uppermost surface of roller cutter 20A as shown in Figure 3 and intersection point 23 of the rotational axis 21 of roller cutter 20A with leg 16. Orifice 37 is at a height H as shown in Figure 3 above the center 35 of corner surface 33. At the jet or orifice exit, the drilling fluid has a maximum velocity and minimal cross sectional area. As the stream or jet travels from the exit point, the stream loses velocity and increases in cross section area. A reduction in velocity reduces the cleaning effectiveness of the stream of drilling fluid. A suitable height should provide an adequate size flow zone from the distribution of the stream with a sufficient velocity and dispersion to effectively clean the cutting elements and the formation.

It is desirable for the sweeping of the drilling fluid stream inwardly beneath the cutting elements on the associated cutter 20A that a substantial portion of the drilling fluid stream 44 contacts side wall 34 of the bore hole 30. It is also important that the velocity of the drilling fluid stream 44 not be materially reduced after impacting corner surface 33 so that a high velocity is maintained for the subsequent sweeping action between the side wall and cutting elements at the cutting engagement area of the cutting elements with the side wall and bore hole corner, and then for the sweeping action along the bottom surface at the cutting engagement areas of the cutters. To maintain a maximum velocity of fluid stream 44, discharge orifice 37 should be located as close as possible to side wall 34 with the center 41 of the discharge exit spaced a distance D as indicated in Figures 3 and 6 not greater than around 1 inch from side wall 34 and preferably around 1/2 inch. As a result the fluid stream can be directed to undergo a minimum change in angular direction as its sweeps across the corner surface and the hole bottom. A minimal

change in direction of stream 44 is desirable to minimize viscous drag and to maintain maximum velocity. For this purpose assuming the hole bottom surface to be perpendicular to the side wall surface, a change in direction of fluid stream 44 may be as small as 90 degrees but should not exceed 100 degrees for best results.

Figure 7 illustrates a vertical plane P though the rotational axis 21 of roller cutter 20A and the center exit 41 of orifice 37 is offset a distance D1 from plane P. The maximum radius of the body of roller cutter 20A not including the projecting portions of cutting elements 26 is indicated at R in Figure 7. For best results, the center exit 41 of orifice 37 is located at a lateral distance D1 greater than the radius R from the axis of rotation so that a majority of the fluid stream may be directed against the corner surface 33 instead of the gage forming surface of roller cutter 20A.

In order to maintain the high velocity stream 44 in a direction tangential to the formation surface with a maximum volume for sweeping across bottom surface 32 underneath cutter 20A, a majority of the fluid stream 44 should impact the formation at or above corner surface 33. Also, in order for stream 44 to fan out sufficiently for sweeping under most of cutter 20A so as not to lose much velocity, it is believed that orifice 37 should be spaced a height H from the center 35 of corner surface 33 not more than 2/3 the diameter of the bit. Thus, for an 8-3/4 inch diameter bit, height H should not be greater than around 6 inches. In any event, orifice 37 should not be positioned at a height below the intersection 23 of roller cutter 20A with leg 16. Fluid stream 44 flows downwardly with a substantial side portion of the stream contacting side wall 34. The center of fluid stream 44 flows along the hole bottom surface 32 as illustrated by centerline 45 of the fluid stream as shown particularly in Figure 5. Nozzle 36A and orifice 37 are also positioned for directing more hydraulic energy against the cutting elements 26 in gage row 28D than against the cutting elements 26 in any other row including interlocking row 28C.

The corner cutting location shown at 35 in Figure 6 is the center of corner surface 33 directly beneath the rotational axis 21 of cutter 20A which is the maximum projection of gage row 28D on the hole bottom. After impacting side wall 34 at 47, stream 44 sweeps along corner surface 33, then across the hole bottom surface 32 at a high velocity generally tangential to the surface of the formation.

As shown in Figure 6, a side portion of stream 44 contacts the side wall 34 before the cutting elements 26 in row 28D engage the formation at upper point 31A in cutting relation and before impact of the stream 44 against corner surface 33 at point 47. Additionally, as shown in Figures 3 and 6 a substantial portion of stream 44 contacts reaming surface 29 and cutting elements 28E in reaming row 28E for cleaning the gage surface thereat. After impacting side wall 34 at 47, stream 44 is directed by side wall 34 behind cutting elements 26 in gage row 28D and cutting elements 28E in reaming row 28E, then along corner surface 33, and inwardly across bottom surface 32 tangential to the formation. Thus, after impacting corner surface 33 at 47, stream 44 closely follows the contour of corner surface 33 and bottom surface 32 in a thin high velocity stream thereby providing a relatively thin high velocity stream sweeping between the formation and cutting elements at numerous cutting engagement locations of rows 28D, 28C, 28B, and 28A for maximum cleaning effectiveness.

The nozzle orifices 37 are made of tungsten carbide or other suitable erosion resistant material and are positioned a distance H as shown in Figure 3 above impact point 47 on corner surface 33. Orifice 37 is preferably positioned between the upper surface of cutter 20A and intersection 23 of rotational axis 21 with leg 16 but may, under certain conditions, be located below intersection 23 or above the upper surface of nozzle 20A. Nozzles 36A, 36B, 36C are each positioned closely adjacent respective roller cutters 20A, 20B and 20C. Nozzle 36A, for example, is positioned close to the leading side of roller cutter 20A with respect to the direction of bit rotation. Roller cutters 20A, 20B, and 20C are spaced in a circular path at intervals of 120 degrees.

Referring to Figures 8 and 9, a modified nozzle configuration is shown in which bit body 12H includes a roller cutter 20H having a gage row 28H of cutting elements and a reaming row 28I of cylindrical cutting elements. A stream 44H of drilling fluid is provided from passage 29H and fluid discharge tube 46H. The centerline 45H of the stream 44H of drilling fluid from nozzle 36H at the end of the tube 46H is slightly slanted toward the side wall 34H preferably at a radial angle less than around 10 degrees with the impact point 47H being above corner surface 33H. Nozzle 36H has an orifice 37H which discharges a stream of fluid with the centerline 45H impacting side wall 34H above the center 35H of corner surface 33H a distance H1 of around 1 inch for example, as shown in Figure 8. The center 41H of orifice 37H is spaced a distance D2 from side wall 34H which is less than around one inch. Flow passage 29H directs fluid stream 44H at an angular relation to side wall 34H for impacting side wall 34H at 47H. Fluid stream 44H is flattened by side wall 34H and flows downwardly along the surface of side wall 34H, across corner surface 33H at the cutting and gage contacting areas of the gage row and reaming row. As a

result of slightly slanting flow passage 29H toward side wall 42H, the fluid stream 44H is disposed along the side wall in a wider stream for sweeping across corner surface 33H at the cutting and gage engaging areas of the gage row and reaming row.

Referring now to Figure 10, an additional embodiment of this invention is shown in which a bit body 12R has a roller cutter 20R positioned adjacent side wall 34R and corner surface 33R. Roller cutter 20R has a gage row 28R of cutting elements and a reaming row 28S of cutting elements similar to roller cutter 20A of the embodiment of Figures 1-7. A fluid discharge tube 46R leads from fluid passage 29R in bit body 12R. A discharge nozzle 36R has a discharge orifice 37R for fluid stream 44R having a centerline 45R for the center of the volume of discharged fluid. Discharge nozzle 36R is positioned at the outer circumference of bit body 12R with discharge orifice 37R being positioned a distance less than one inch from side wall 34R as in the embodiments of Figures 1-7 and Figures 8 and 9. The longitudinal axis of discharge tube 46R is angled toward the center of roller cutter 20R at the lowermost projection point of the cutting elements in gage row 28R with the formation at corner surface 33R. The center 45R of stream 44R impacts side wall 34R at impact point 47R generally above the maximum vertical projection of the cutting elements in gage row 28R indicated at 39R. Thus, stream 44R sweeps across corner surface 33R at the area of maximum cutting engagement by the gage row 28R of cutting elements and also across the reaming row 28S of cutting elements.

From the foregoing, it is apparent that an improved rate of penetration may be obtained by the improved cleaning and hydraulic action provided by the positioning of fluid discharge orifices along the outer circumference of a drill bit body spaced less than around one inch from the bore hole side wall for the discharge of a high velocity stream of drilling fluid having at least a substantial side portion thereof contacting and flowing along the side wall surface in opposed relation to an associated roller cutter for sweeping across the corner surface at the cutting engagement area of the cutting elements in the gage row and the gage forming area of the reaming row with the formation. The high velocity stream in one embodiment has the center of the fluid volume impacting the corner surface while other embodiments have the center of the stream impacting the side wall surface above the corner surface. As a result of having the nozzle orifice positioned closely adjacent the side wall surface the stream undergoes a minimum change in direction as it sweeps across the corner surface and along the hole bottom while maintaining a maximum velocity. Also the stream is provided direct access to the cutting elements behind the roller cutter of the reaming and gage rows at the cutting engagement area of the gage row and the gage forming engagement area of the reaming row during contact with the formation. Such a positioning of the nozzle orifices for impacting the corner surface and adjacent side wall surface provides an improved cleaning and scouring action at specific predetermined cutting and gage forming engagement areas.

It is apparent that the nozzle orifice may under certain conditions be positioned a substantial distance from the body of the adjacent roller cutter and yet function in a satisfactory manner for the discharge of the high velocity stream depending on various factors, for example, as the height of the orifice above the bore hole bottom and the slanting of the stream toward the roller cutter such as shown in Figure 10.

While preferred embodiments of the present invention have been illustrated, it is apparent that modifications and adaptations of the preferred embodiments will occur to those skilled in the art. However, it is to be expressly understood that such modifications and adaptations are within the spirit and scope of the present invention as set forth in the following claims.

Claims

1. A rotary drill bit for drilling a bore hole comprising:

   a bit body having an upper end adapted to be connected to a drill string for rotating the bit and for delivering drill fluid to the bit, and having a plurality of legs extending from the lower end thereof, each leg including a journal on the extending end thereof having a longitudinal axis extending downwardly and generally radially inwardly of said leg;

   a roller cutter mounted for rotation about the longitudinal axis of each journal and having a body including a plurality of rows of cutting elements including an outer gage row;

   said gage row of cutting elements adapted to cut the side wall of said well bore, the outer periphery of the bottom surface of said well bore, and the corner surface of said bore hole extending between said side wall and said outer periphery of said bottom surface; the remaining inner rows of cutting elements adapted to cut the remaining inner portion of said bottom surface; and

   a nozzle positioned adjacent a roller cutter at the outer circumference of said bit body and having a nozzle orifice with a center exit spaced less than around one inch from the adjacent side wall and offset laterally from the centerline of said roller cutter body;

said nozzle orifice being constructed and positioned to accelerate and direct a high velocity stream of drilling fluid downwardly along said side wall with at least a substantial side portion of said stream being directed toward and contacting said side wall for flowing downwardly along said side wall and across the bore hole corner surface, the center of said stream impacting the formation above the bottom surface so that a majority of the fluid flows across the corner surface and the bottom surface.

2. A rotary drill bit as set forth in claim 1 wherein the center of said high velocity fluid stream is directed downwardly in a generally vertical direction for impacting said corner surface.

3. A rotary drill bit as set forth in claim 1 wherein the center of the volume of said high velocity stream impacts said side wall above said corner surfaces and then sweeps across said corner surface in a thin high velocity stream.

4. A rotary drill bit as set forth in claim 1 wherein said nozzle orifice is positioned toward the leading side of said adjacent roller cutter.

5. A rotary drill bit as set forth in claim 1 wherein the center of said nozzle orifice exit is offset laterally from a vertical plane through the rotational axis of said roller cutter a distance greater than the maximum radius of said roller cutter body.

6. A rotary drill bit as set forth in claim 5 wherein the center of said nozzle orifice exit is positioned at a height above the intersection of said adjacent roller cutter with its associated leg and not greater than 2/3 the diameter of said bit.

7. A rotary drill bit as set forth in claim 6 wherein the change in direction of the fluid stream after exiting said nozzle orifice and sweeping across said corner surface and hole bottom surface is less than around 100 degrees as measured with said bottom surface being perpendicular to said side wall surface.

8. A rotary drill bit as set forth in claim 7 wherein said fluid stream directs more hydraulic energy against said gage row of cutting elements than against any other rows of cutting elements.

9. A rotary drill bit for drilling a bore hole comprising:

a bit body having an upper end adapted to be connected to a drill string for rotating the bit and for delivering drill fluid to the bit, and having a plurality of legs extending from the lower end thereof, each leg including a journal on the extending end thereof having a longitudinal axis extending downwardly and generally radially inwardly of said leg;

a roller cutter having a body mounted for rotation about the longitudinal axis of each journal and a plurality of rows of cutting elements including an outer gage row of projecting cutting elements and an adjacent reaming row of generally cylindrical cutting elements, said reaming row and adjacent gage contacting surface forming the gage of said bore hole;

said gage row of cutting elements adapted to cut the side wall of said well bore, the outer periphery of the bottom surface of said well bore, and the corner surface of said bore hole extending between said side wall and said outer periphery of said bottom surface, the remaining inner rows of cutting elements adapted to cut the remaining, inner portion of said bottom surface; and

a nozzle positioned adjacent a roller cutter at the outer circumference of said bit body and having a nozzle orifice with a center exit spaced less than one inch from the adjacent side wall and offset laterally from the centerline of said roller cutter body a distance greater than the maximum radius of said roller cutter body;

said nozzle orifice being constructed and positioned to accelerate and direct a high velocity stream of drilling fluid downwardly along said side wall with at least a substantial side portion of said stream being directed toward and contacting said side wall for flowing downwardly along said side wall between said side wall and said gage and reaming rows of cutting elements, a majority of the high velocity stream then sweeping across said corner surface and the bottom surface.

10. A rotary drill bit as set forth in claim 9 wherein the change in direction of the fluid stream after exiting said nozzle orifice and sweeping across said corner surface and hole bottom surface is less than around 100 degrees as measured with said bottom surface being perpendicular to said side wall surface.

11. A rotary drill bit as set forth in claim 10 wherein said fluid stream directs more hydraulic energy against said gage row of cutting elements than against any other rows of cutting elements.

12. A rotary drill bit as set forth in claim 9 wherein the center of the volume of said high velocity stream impacts said side wall above said corner surface and then sweeps across said corner surface in a thin high velocity stream.

13. A rotary drill bit as set forth in claim 9 wherein the center of the volume of said high velocity stream is inclined radially toward the side wall less than 10 degrees.

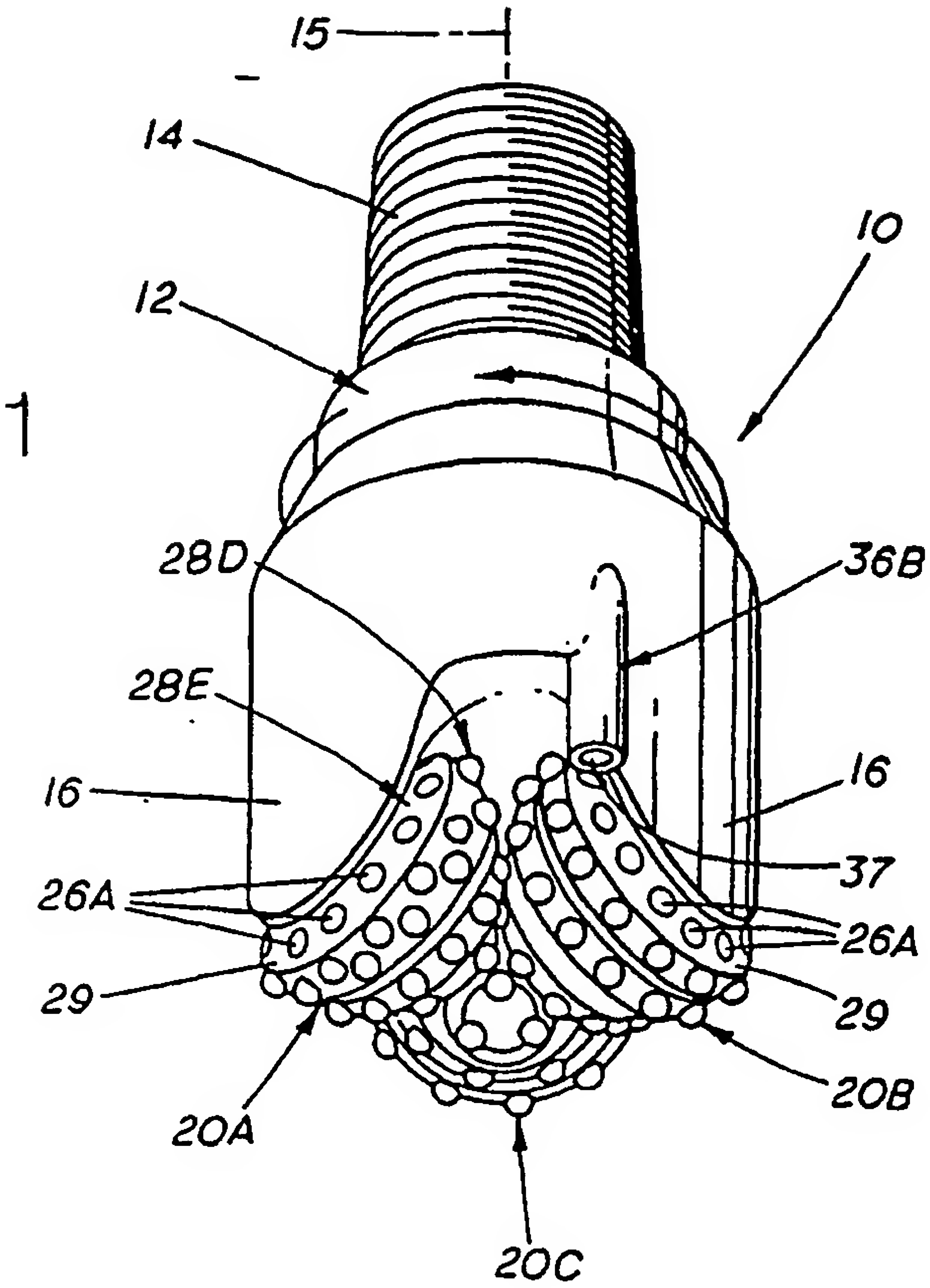
15
14
10
12
28D
36B
28E
16
16
37
26A
26A
29
29
20A
20B
20C

FIG.1

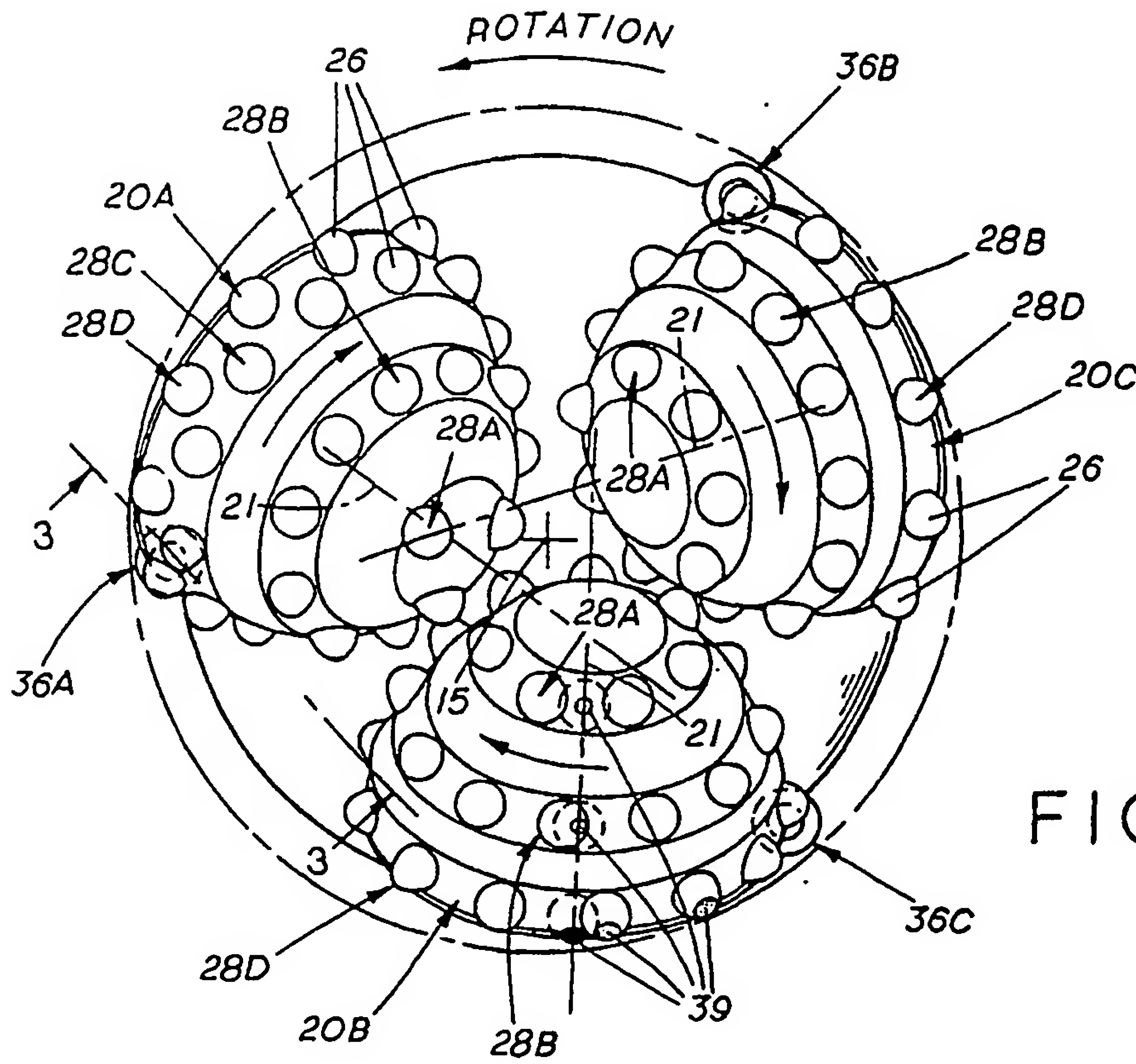
ROTATION
26
36B
28B
20A
28B
28C
28D
28D
21
20C
28A
26
21
28A
3
28A
36A
15
21
3
36C
28D
20B
28B
39

FIG.2

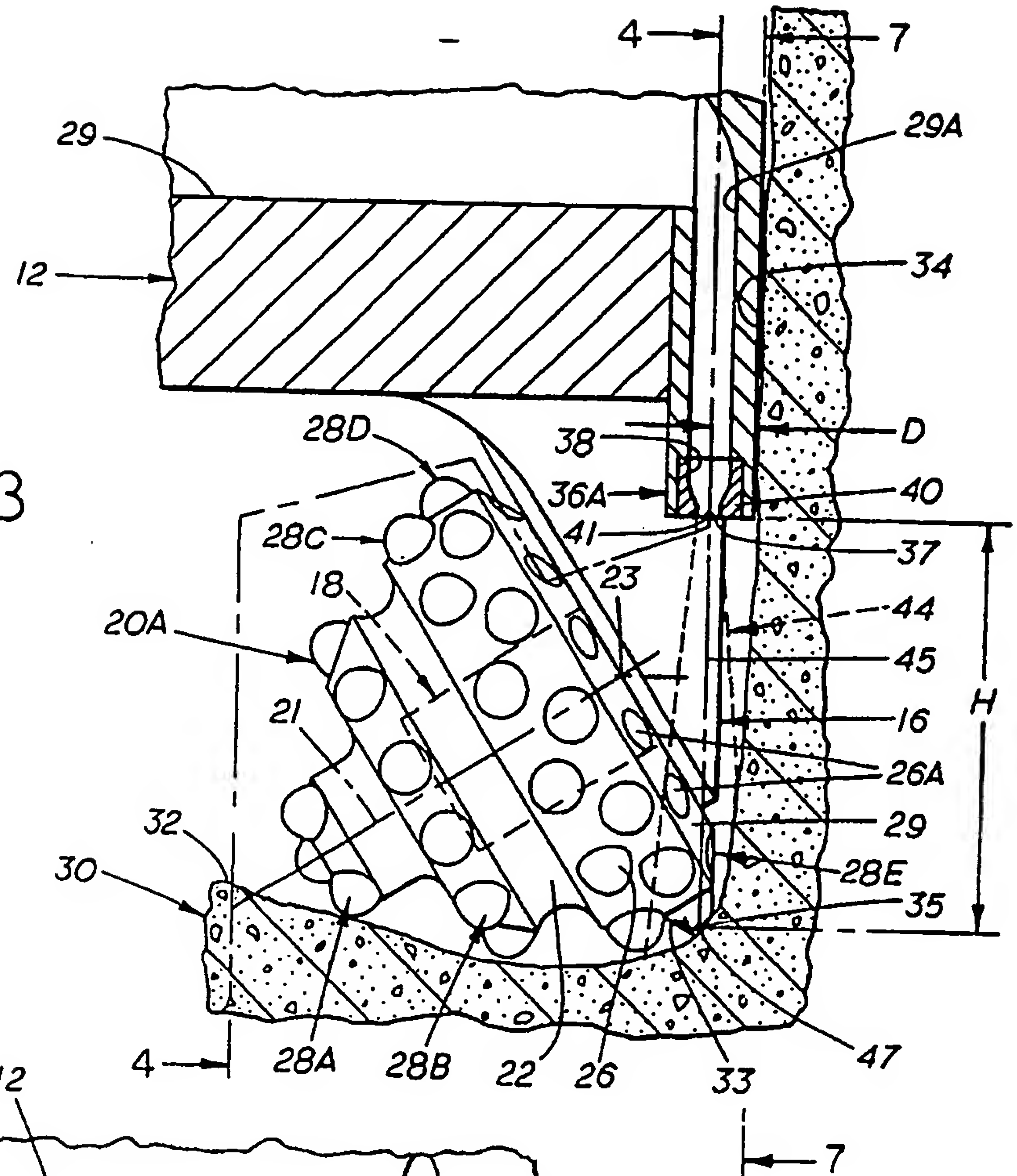
4
7
29
29A
12
34
28D
38
D
36A
40
41
37
28C
23
18
44
20A
45
H
21
16
26A
32
29
30
28E
35
4
28A
28B
22
26
33
47
7

FIG. 3

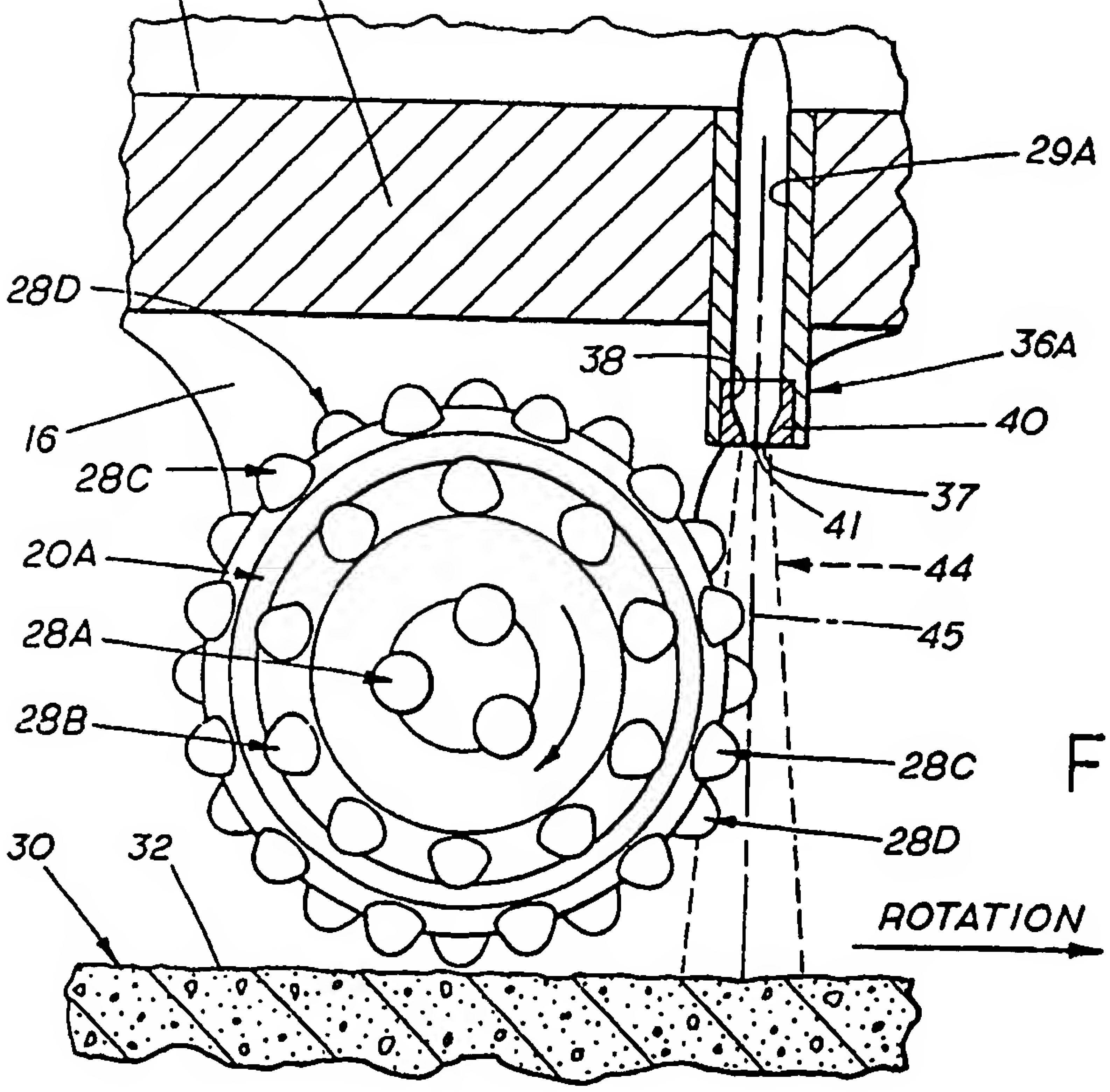
29
12
29A
28D
36A
38
40
16
28C
37
41
20A
44
28A
45
28B
28C
28D
30
32
ROTATION

FIG. 4

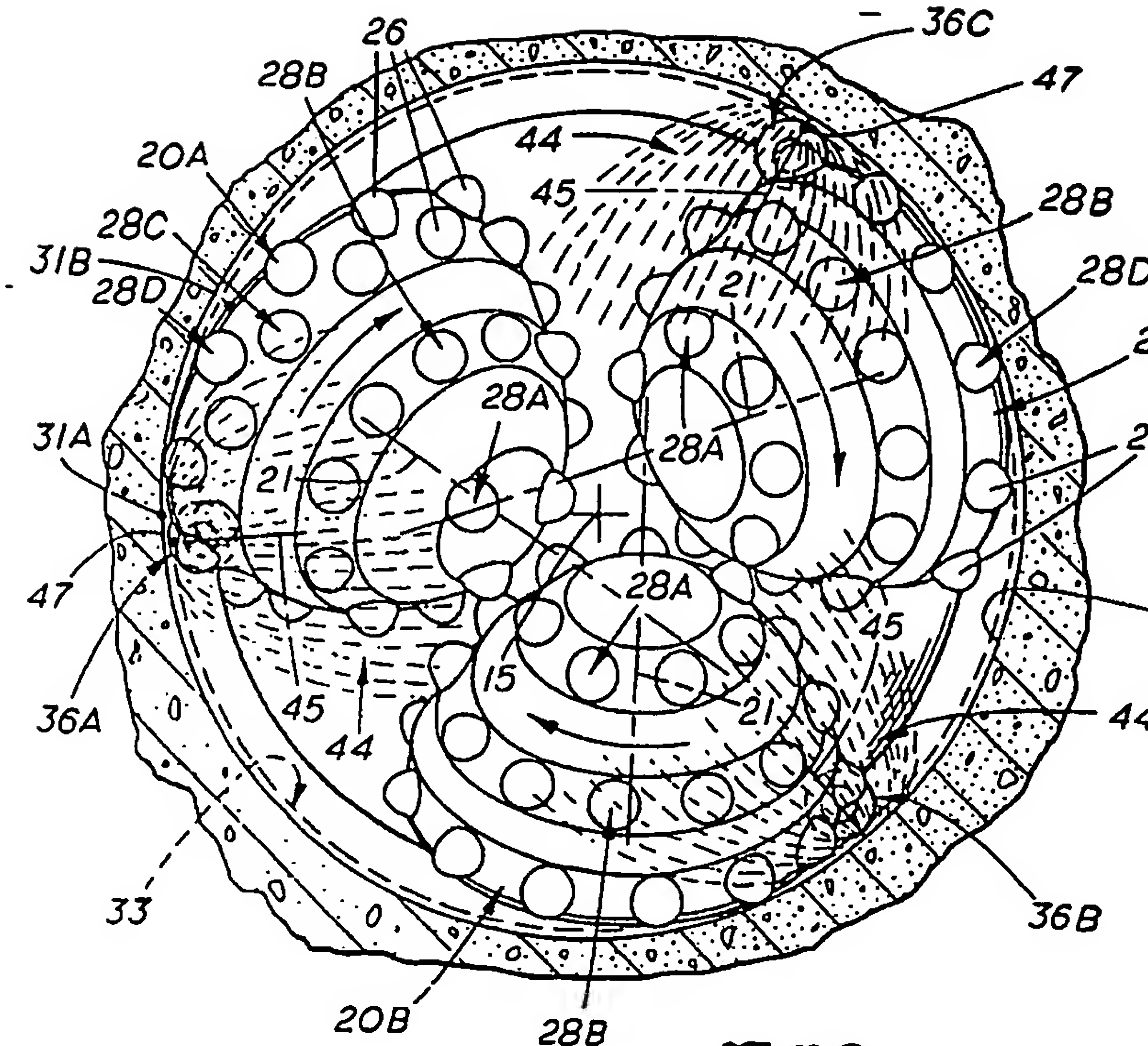
26
28B
36C
47
20A
44
45
28B
28C
31B
28D
21
28D
20C
28A
31A
21
28A
26
28A
47
45
34
36A
45
44
15
21
44
33
36B
20B
28B

FIG.5

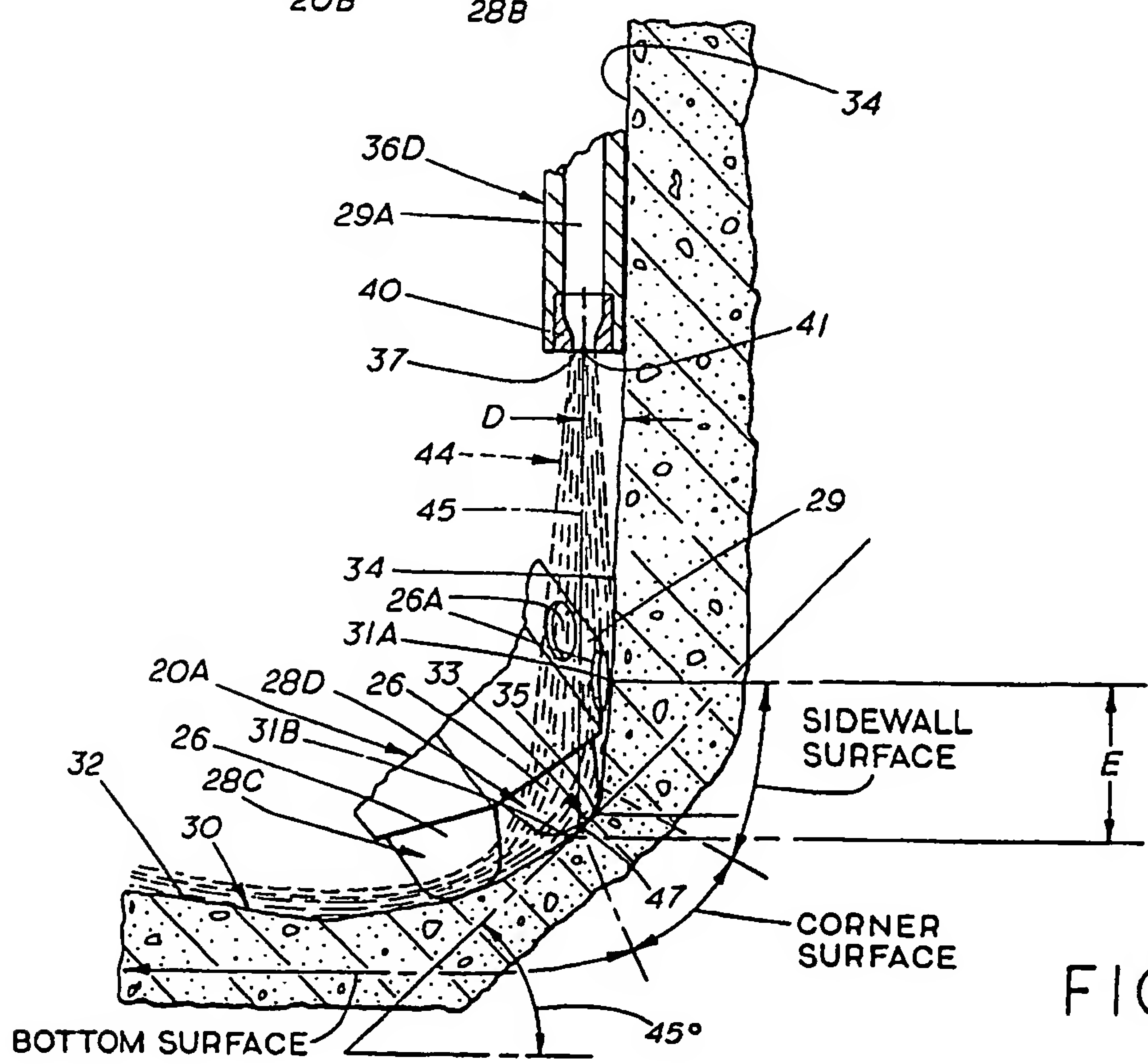
34
36D
29A
40
41
37
D
44
45
29
34
26A
31A
20A
28D
26
33
35
SIDEWALL
SURFACE
E
26
31B
32
28C
30
47
CORNER
SURFACE
BOTTOM SURFACE
45°

FIG.6

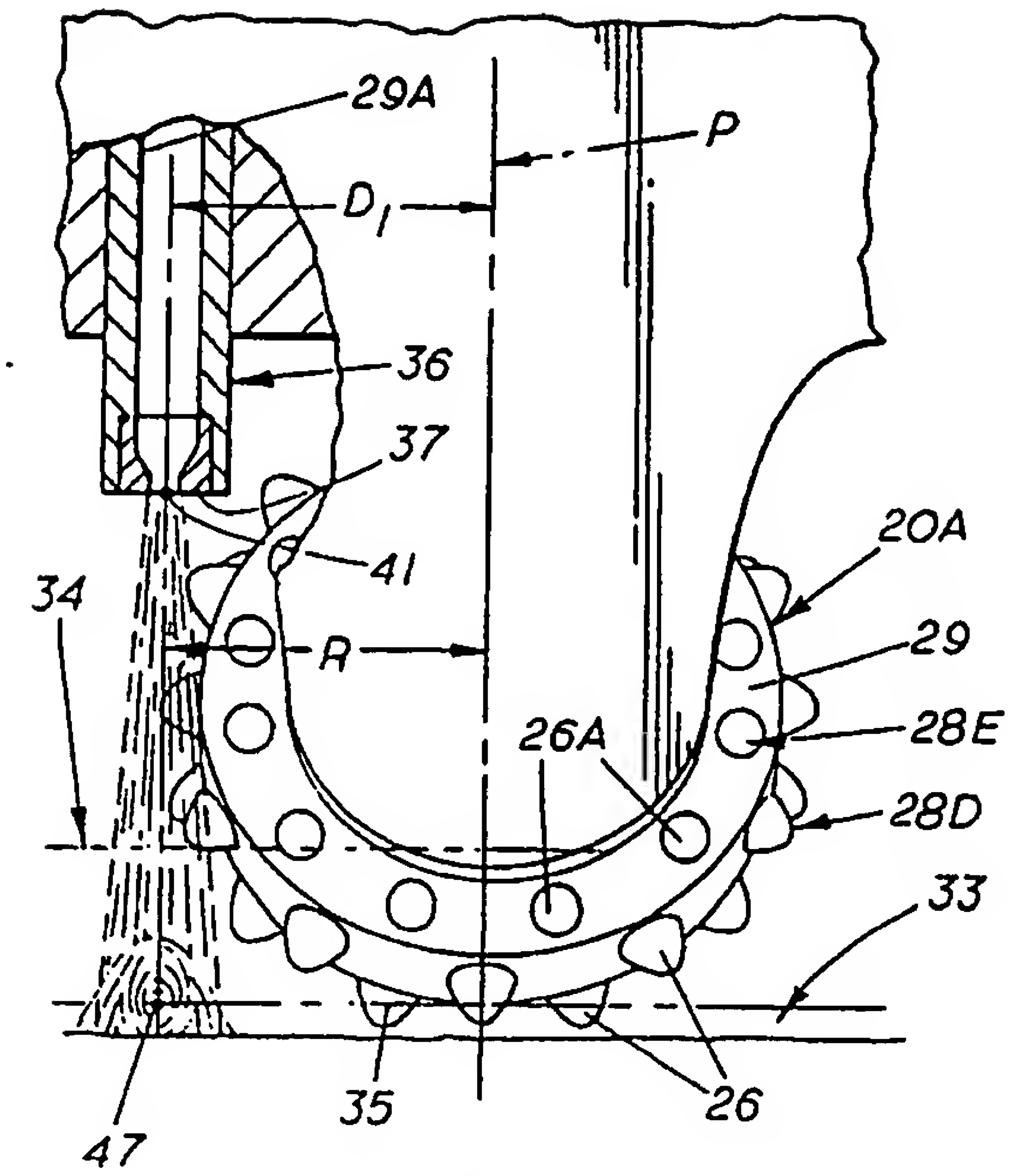

FIG.7

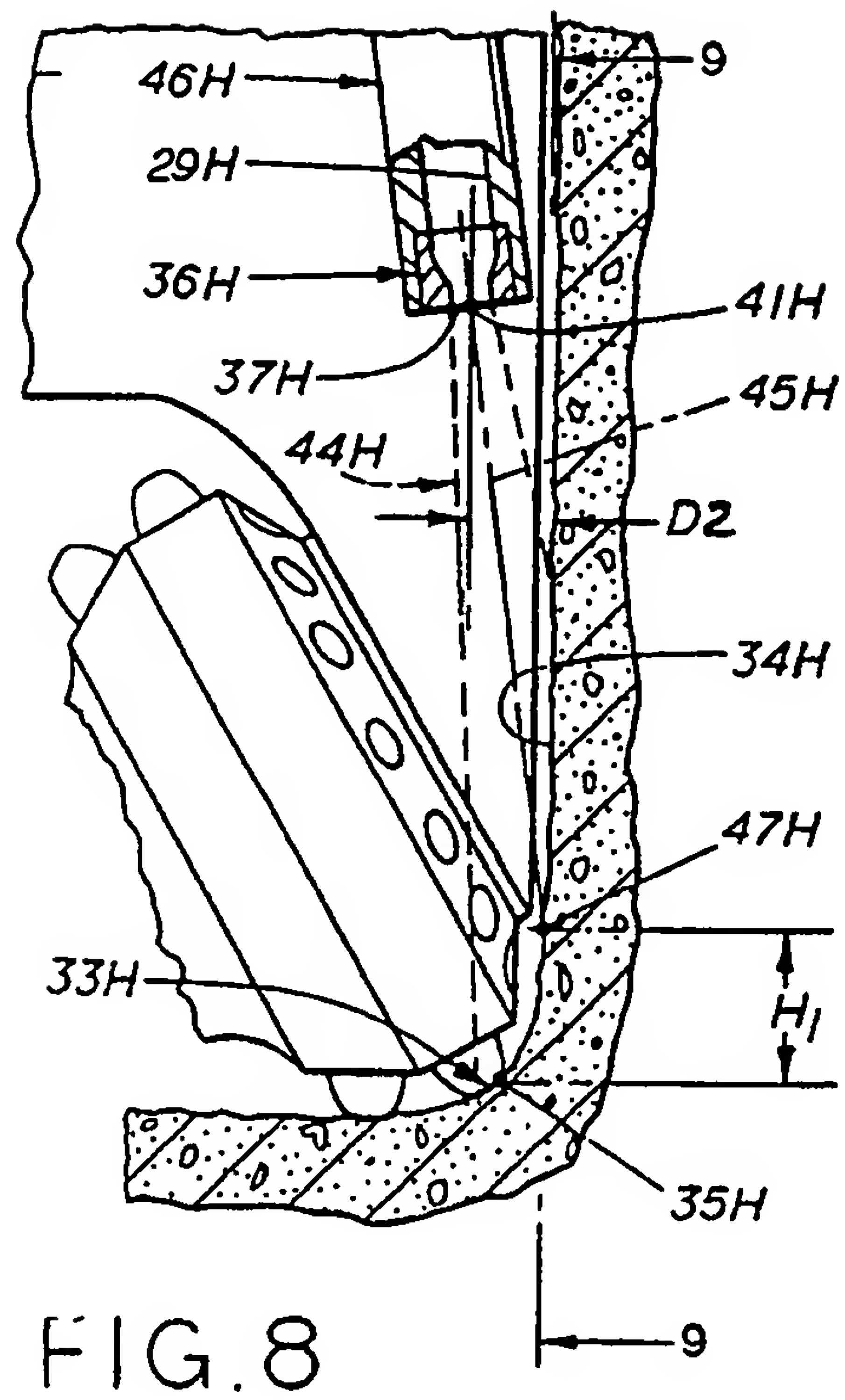

FIG.8

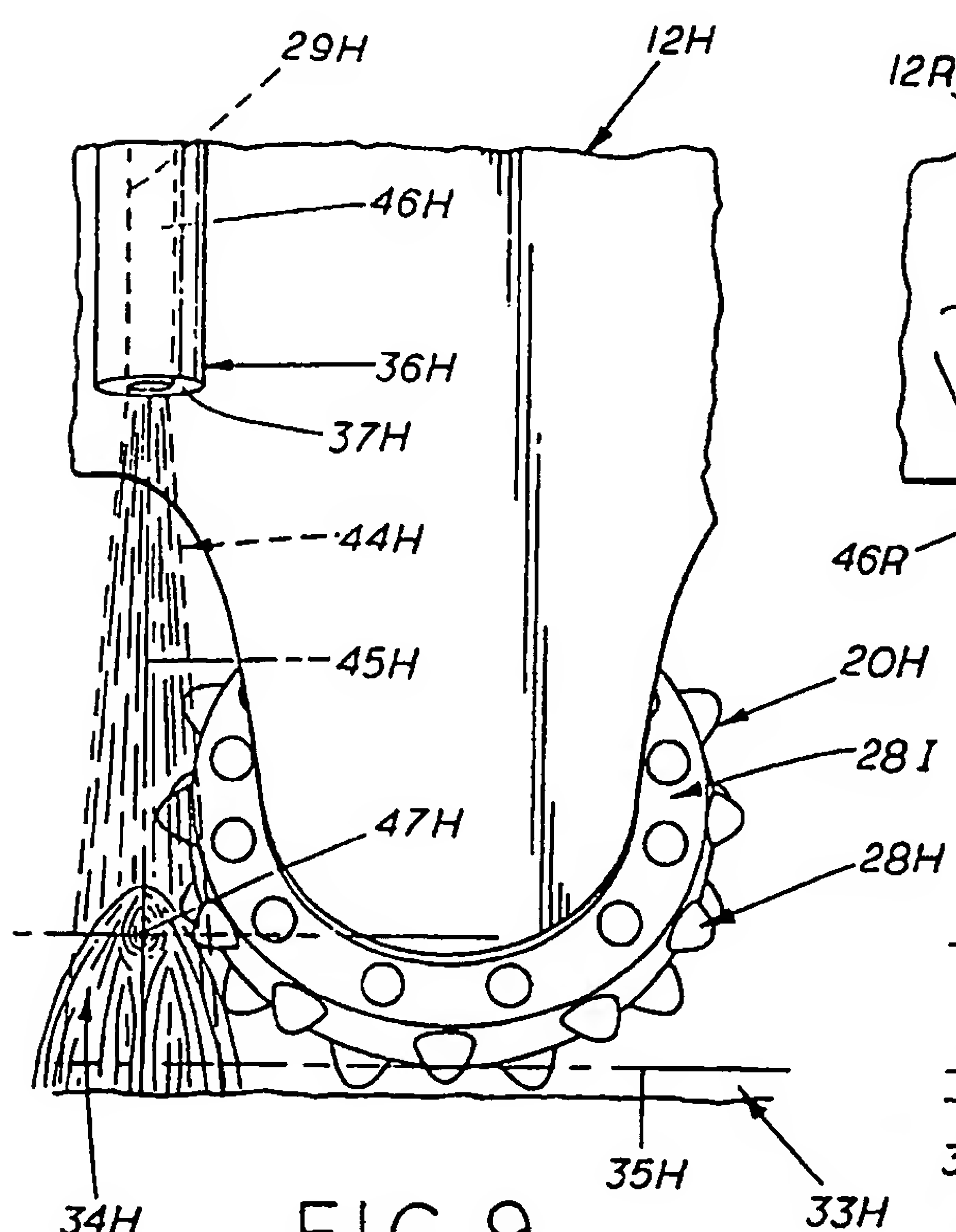

FIG.9

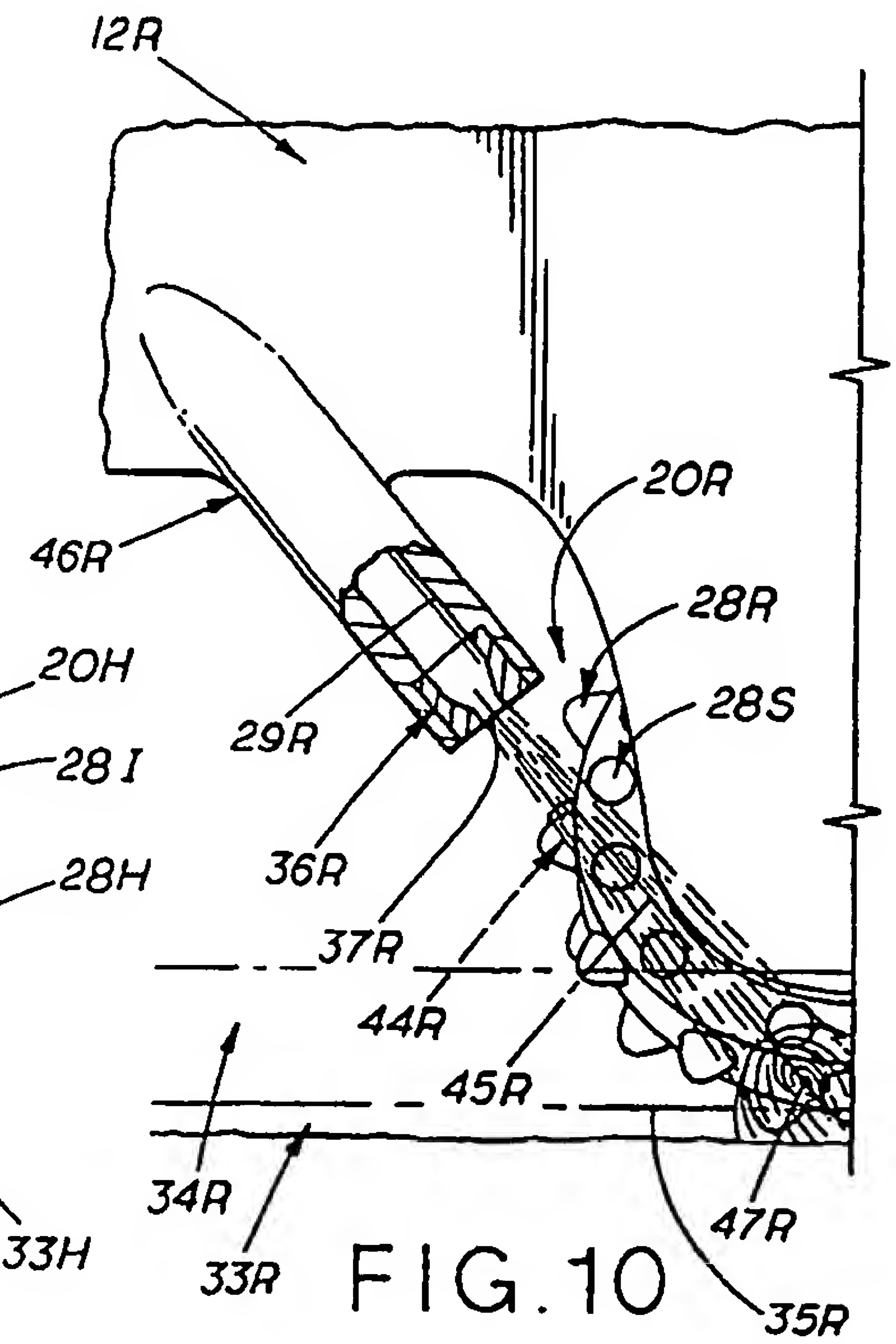

FIG.10

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